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COMPARISON OF COMPLIANCE RESULTS FOR THE WEDGE-LOADED COMPACT SPECIMEN

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US ARMY ARMAMENT RESEARCH, DEVELOPMENT AND ENGINEERING CENTER

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Results of the ratio of stress intensity factor to crack mouth displacement as a function of crack length are presented for the wedge-loaded compact specimen. Comparisons are made between experimental compliance results, numerical results from collocation methods, and deep crack limit solution results. Applications are for crack arrest and stress corrosion cracking tests for metals and other materials under predominantly linear elastic conditions.
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TABLE OF CONTENTS

INTRODUCTION

The compliance relation for the wedge-loaded compact specimen is the ratio of stress intensity factor to crack mouth displacement, K/δ, as a function of relative crack length, a/W (see Figure 1). This relation is currently used for crack arrest fracture toughness tests (refs 1,2) and is suitable for other tests using wedge loading, such as some stress corrosion cracking tests. The location of δ measurement is removed from the points of loading, so the K obtained from δ is little affected by local irregularities in the loading conditions, such as areas of friction variation on the wedge.

The objective here is to compare two sets of K/δ results, one based on experimental compliance (ref 1) and the other based on collocation calculations (refs 3,4). Each set of results is also compared with the appropriate deep crack limit solution, and discussion is offered regarding the accuracy of the two sets of results.

ANALYSIS

The basis of the comparison is the following dimensionless parameter:

$$Y = \frac{KW^{1/2}/\delta E}{(1-a/W)^{1/2}} \tag{1}$$

where E is the elastic modulus. This parameter was used because it is the form of the deep crack limit solution (ref 5) for this specimen type

$$\lim_{a/W \to 1} \frac{KW^{1/2}/\delta E}{(1-a/W)^{1/2}} = 0.2013 \tag{2}$$

References are listed at the end of this report.

This form has the important property of remaining within the range 0.20 to 0.35 over the a/W range of interest. Comparison is not impaired by values tending toward 0 or ∞, hence maximum resolution is possible.

The comparison of Y versus a/W results from experiment and collocation is shown in Figure 2 and Table I. Equation (3), obtained from the experimental compliance results of Reference 1 and specified as the K/δ relation for Reference 2, is

$$Y = \frac{2.24(1.72 - 0.9\ a/W + a/W^2)}{9.85 - 0.17\ a/W + 11\ a/W^2} \tag{3}$$

$$0.35 < a/W < 0.85$$

Equation (4), fitted to the collocation results of References 3 and 4, is

$$Y = 0.748 - 2.176\ a/W + 3.56\ a/W^2 - 2.55\ a/W^3 + 0.62\ a/W^4 \tag{4}$$

$$0.2 < a/W < 1$$

The deep crack limit solution (ref 5) is also shown in Figure 2 and Table I for a/W = 1.

The comparison shows that the two sets of results agree well for a/W between 0.4 and 0.6 and diverge for lower and higher a/W. The difference for low a/W may be caused by differentiation of compliance data near the end point of the data, an inherent limitation of the experimental compliance method. This difference between the results at low a/W is of little concern because these low values of a/W are not used to calculate crack arrest fracture toughness and are seldom used in other tests. For high a/W, the maximum difference between the two results is more than 6 percent at an a/W of about 0.8. Unlike some other fracture tests, this high value of a/W is important for the crack arrest test because many of the final, most critical measurements are made at an a/W of about 0.8.

TABLE I. COMPARISON OF K/δ RESULTS FOR WEDGE-LOADED COMPACT SPECIMENS

$$\frac{KW^{1/2}/\delta E}{(1-a/W)^{1/2}}$$

a/W	Collocation Data Refs (3,4)	Experimental Compliance Eq. (3)	Difference From Collocation Data %	Collocation Eq. (4)	Difference From Collocation Data %
0.2	0.4360	-	-	0.4358	0
0.3	0.3526	-	-	0.3518	-0.2
0.4	0.3001	0.2950	-1.7	0.2999	-0.1
0.5	0.2703	0.2721	+0.7	0.2700	-0.1
0.6	0.2543	0.2516	-1.1	0.2536	-0.3
0.7	0.2443	0.2341	-4.2	0.2434	-0.4
0.8	0.2339	0.2193	-6.2	0.2340	0
	Limit; Eq. (2):				
1.0	0.2013	0.1971	-2.1	0.2020	+0.3

One possible cause of the disagreement at high a/W is the two-dimensional nature of the collocation analysis as opposed to the three-dimensional experiments which involved the use of side grooves (ref 1). However, any effects of this general difference between experiment and analysis would be expected over the whole range of a/W, not just at high a/W. Another possible cause which can be eliminated on this same basis is the use of collocation displacements with the wrong choice of boundary conditions. Regardless of the choice, plane-stress or plane-strain, discrepancies only at high a/W would not be expected. In Eq.

(4), Newman's plane-stress displacements (ref 4) were used because crack mouth displacement is a global parameter.* If plane-strain displacements had been used, the difference between experiment and analysis would have been about 15 percent rather than 6 percent.

Two aspects of compliance experiments which can result in errors, particularly for large a/W, are notch width and plastic zone effects. Both the width of the notch and the plastic zone at the notch tip can become significant in size relative to the remaining ligament, (W-a), which is the controlling dimension at large a/W. Furthermore, both of these effects could be expected to increase the effective notch length, thus increasing δ and decreasing Y. This could explain the disagreement between experiment and analysis. The experiment, even though it is a direct model of the physical problem, is unfortunately subject to notch and plastic zone effects which limit the accuracy of the model.

CONCLUSIONS

In conclusion, it is evident that the K/δ expression based on collocation results, Eq. (4), is more accurate than the experimental compliance expression, particularly for large a/W. Equation (4) is believed to be accurate to within 1 percent over the range $0.2 < a/W < 1$. The collocation results agree well with the experiment for intermediate a/W, where experimental compliance methods can be used as a direct check on analysis. At large a/W the collocation results converge closely upon the deep crack limit solution, whereas the experimental results are affected by inherent experimental difficulties.

*A plane-stress crack mouth displacement analysis is considered to be correct here because most of the specimen is allowed to deform in the thickness direction. Only a small portion of the specimen near the crack tip is subjected to plane-strain conditions and the associated constraint in the thickness direction. This small portion has little effect on the global crack mouth displacement.

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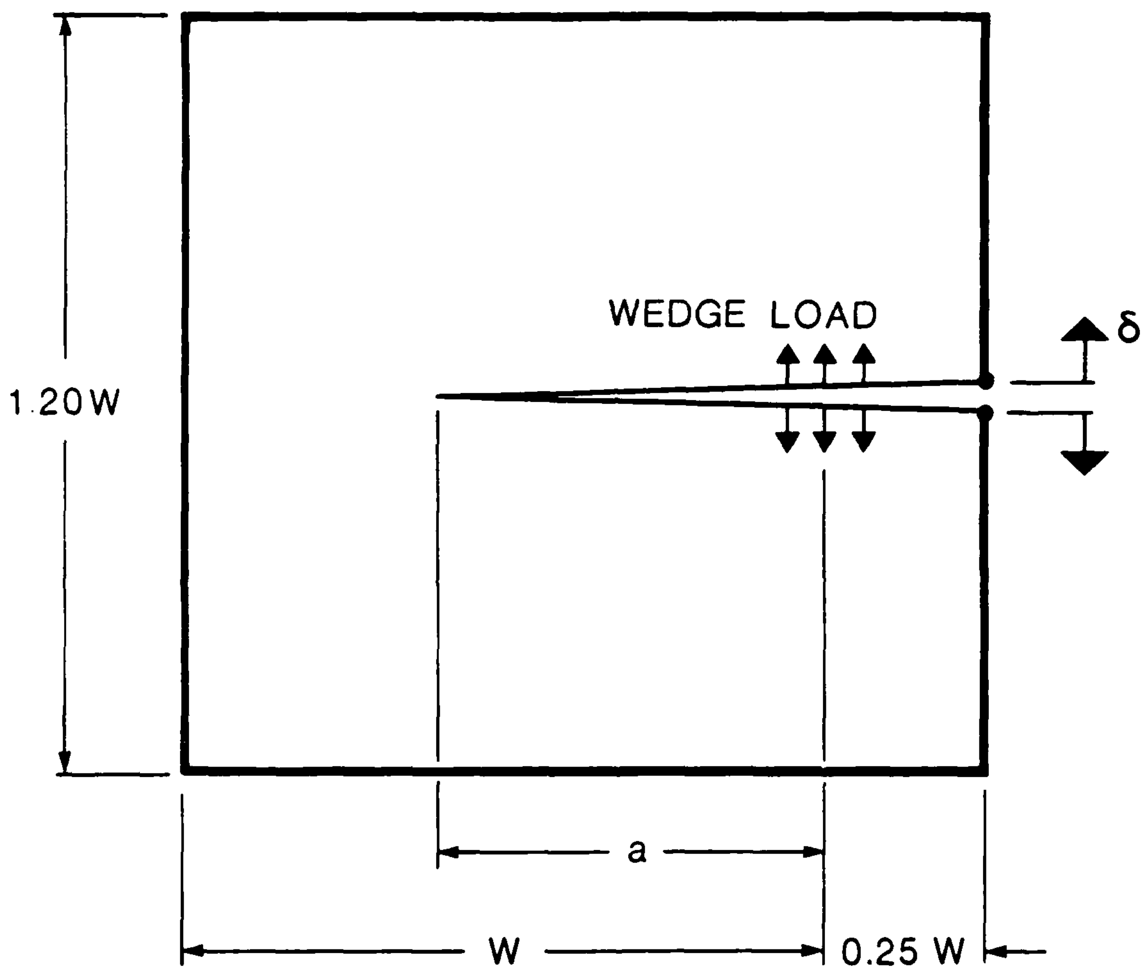

Figure 1. Wedge-loaded compact specimen geometry.

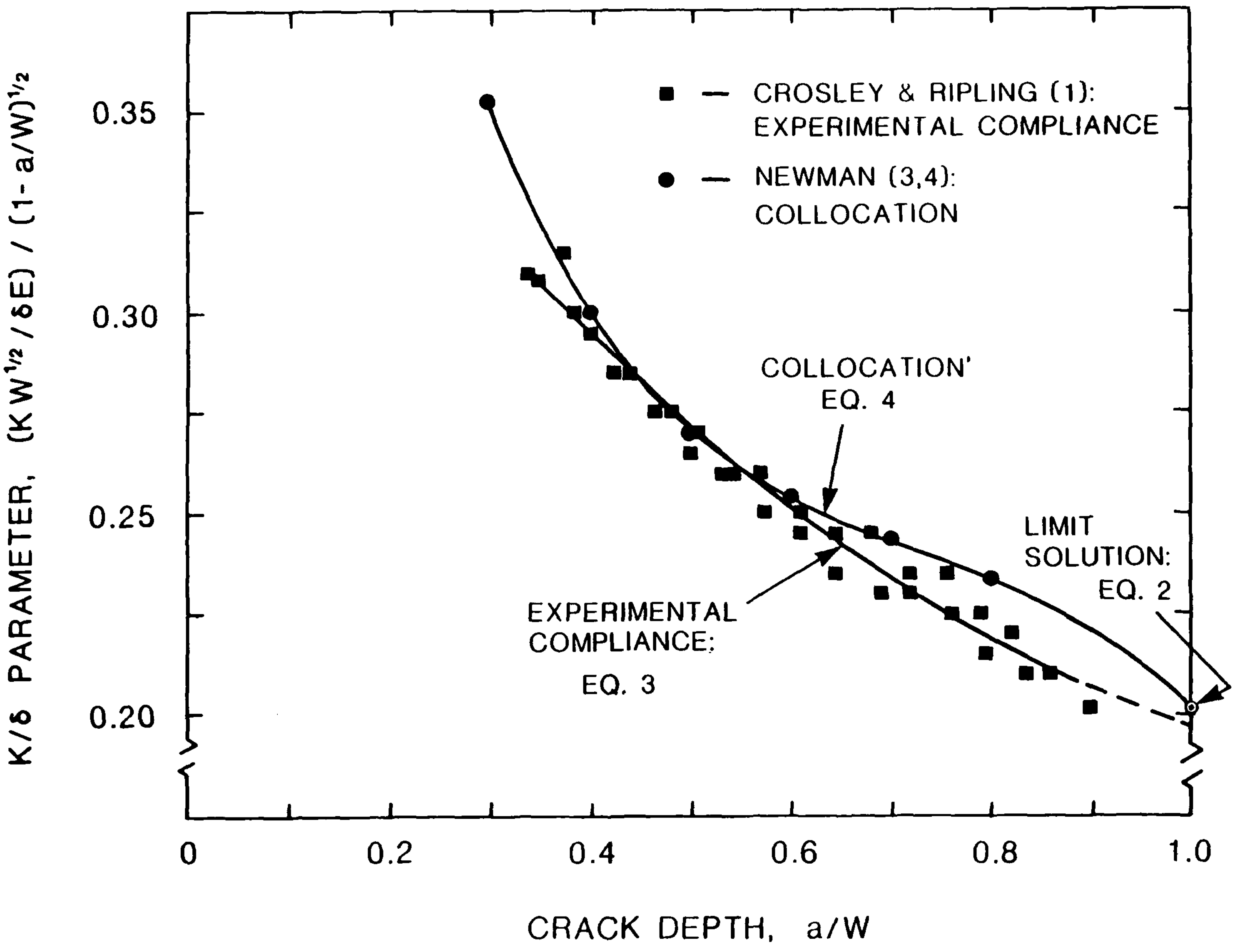

Figure 2. Ratio of stress intensity factor to crack mouth displacement, K/δ, for wedge-loaded compact specimen.

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